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ORIGIN AND MECHANISMS OF CP VIOLATION

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Origin and Mechanisms of CP Violation

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Abstract

It is shown that the mechanism of spontaneous symmetry breaking provides not only a mechanism for giving mass to the bosons and the fermions, but also a mechanism for generating CP-phase of the bosons and the fermions. A two-Higgs doublet model with Vacuum CP Violation and Approximate Global $U(1)$ Family Symmetries (AGUFS) is built and may provide one of the simplest and attractive models in understanding origin and mechanisms of CP violation at the weak scale. It is seen that CP violation occurs everywhere it can from a single CP phase of the vacuum and is generally classified into four types of CP-violating mechanism. A new type of CP-violating mechanism is emphasized and can provide a consistent application to both the established and the reported CP-, T- and P-violating phenomena.

Keywords:

Vacuum CP Violation (VCPV); Approximate Global U(1) Family Symmetries(AGUFS); Partial Conservation of Neutral Flavor (PCNF); New Type of CP-Violating Mechanism; Two-Higgs Doublet Model (2HDM); Spontaneous Symmetry Breaking (SSB).

In the Standard Model with three families, CP violation is known to occur through a single physical KM-phase[1] in the gauge interactions of the quarks. This phase originally comes from the complex Yukawa couplings. Beyond the Standard Model, CP violation can take place through superweak interactions [2]. It was pointed out by T.D. Lee [3] that CP symmetry could be broken spontaneously, thus the scalar particles are responsible for a CP violation. In the Weinberg three-Higgs doublet model [4], CP violation appears through Scalar-Pseudoscalar Mixings (SPM). Recently, I investigated [5] a simple two-Higgs Doublet Model (2HDM) and observed that there exists a new type of CP-violating mechanism. By this new mechanism, the CP-violating parameters ϵ and ϵ'/ϵ in kaon decay and the neutral electric dipole moment can be consistently accommodated.

Before having definitive experimental test on origin and mechanisms of CP violation, we should consider all the possibilities. In this paper, I shall explicitly show how four types of CP-violating mechanism can be induced from a single CP-violating phase of the vacuum in a simple 2HDM.

Such a 2HDM within the framework of the $SU(2) \times U(1)$ gauge theory is built by considering the two basic assumptions: first, CP violation solely originates from a single CP-violating phase of the vaccum; second, the theory possesses Approximate Global U(1) Family Symmetries (AGUFS) which act only on the fermions. In general, without imposing any additional conditions, the AGUFS will naturally lead to a Partial Conservation of Neutral Flavor (PCNF).

It is known that the first assupmtion can be realized by the Spontaneous CP Violation (SCPV), nevertheless, SCPV encounters so-called domain-wall problem at the weak scale. In order to prevent the domain-wall problem from arising explicitly, we observe the following fact that

In the gauge theories of spontaneous symmetry breaking (SSB), CP violation can be required solely originating from the vacuum after SSB, even if CP symmetry is not good prior to the symmetry breaking. The *demanded condition* for such a statement is: *CP nonconservation occurs only at one place of the interactions in the Higgs potential.* This requirement actually results that the vacuum must violate CP symmetry. In particular, this condition may be simply realized by an *universal rule*. That is, in a renormalizable lagrangian all the interactions with dimension-four conserve CP and only interactions with dimension-two

possess CP nonconservation. It may also be naturally implemented through imposing some symmetries. For convenience of mention, we refer such a CP violation as a Vacuum CP Violation (VCPV).

For a 2HDM, the most interesting case is the one with the universal rule stated above. Then the Higgs potential can be simply written in the following general form

$$\begin{aligned} V(\phi) &= \lambda_1(\phi_1^\dagger\phi_1 - \frac{1}{2}v_1^2)^2 + \lambda_2(\phi_2^\dagger\phi_2 - \frac{1}{2}v_1^2)^2 \\ &+\lambda_3(\phi_1^\dagger\phi_1 - \frac{1}{2}v_1^2)(\phi_2^\dagger\phi_2 - \frac{1}{2}v_2^2) + \lambda_4[(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) - (\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1)] \\ &+\frac{1}{2}\lambda_5(\phi_1^\dagger\phi_2 + \phi_2^\dagger\phi_1 - v_1v_2\cos\delta)^2 + \lambda_6(\phi_1^\dagger\phi_2 - \phi_2^\dagger\phi_1 - v_1v_2\sin\delta)^2 \\ &+[\lambda_7(\phi_1^\dagger\phi_1 - \frac{1}{2}v_1^2) + \lambda_8(\phi_2^\dagger\phi_2 - \frac{1}{2}v_2^2)][\phi_1^\dagger\phi_2 + \phi_2^\dagger\phi_1 - v_1v_2\cos\delta] \end{aligned} \tag{1}$$

where the λ_i $(i = 1, \cdots, 8)$ are all real parameters. If all the λ_i are non-negative, the minimum of the potential then occurs at $< \phi_1^0 >= v_1e^{i\delta}/\sqrt{2}$ and $< \phi_2^0 >= v_2/\sqrt{2}$. It is clear that in the above potential CP nonconservation can only occur through the vacuum, namely $\delta \neq 0$. Obviously, such a CP violation appears as an explicit one in the potential when $\lambda_6 \neq 0$, so that the domain-wall problem does not explicitly arise. Note that in general one can also demand one of other terms, such as λ_5 or λ_7 or λ_8 to be complex in a general potential.

To see the second assumption of the AGUFS, we start with a general Yukawa interaction

$$L_Y = \bar{q}_L\Gamma_D^a D_R\phi_a + \bar{q}_L\Gamma_U^a U_R\bar{\phi}_a + \bar{l}_L\Gamma_E^a E_R\phi_a + H.C. \tag{2}$$

where q_L^i, l_L^i and ϕ_a are $SU(2)_L$ doublet quarks, leptons and Higgs bosons, while U_R^i, D_R^i and E_R^i are $SU(2)_L$ singlets. $i = 1, \cdots, n_F$ is a family label and $a = 1, \cdots, n_H$ is a Higgs doublet label. Γ_F^a $(F = U, D, E)$ are the arbitrary real Yukawa coupling matrices.

It is known that in the limit that CKM matrix is unity, any models with NFC [6] at tree level generate global $U(1)$ family symmetries, i.e., under the global U(1) transformations for each family of the fermions $(U,\ D)_i \to e^{i\alpha_i}(U,\ D)_i$, the lagrangian is invariant. Where α_i are the constants and depend only on the family index. In the realistic case, it is known that CKM matrix deviates only slightly from unity. This implies that at the electroweak scale any successful models can only possess approximate global $U(1)$ family symmetries.

With this consideration, we are motivated to parameterize the Yukawa coupling matrices in such a convenient way that violations of the global $U(1)$ family symmetries for the charged

currents and the neutral currents can be easily distinguished and the magnitudes of their violations are characterized by the different sets of parameters. This can be implemented explicitly by parameterizing the matrices Γ_F^a in terms of the following general structure

$$\Gamma_F^a = O_L^F \sum_{i,j=1}^{n_F} \{\omega_i (g_a^{F_i} \delta_{ij} + \zeta_F \sqrt{g^{F_i}} S_a^F \sqrt{g^{F_j}}) \omega_j\} (O_R^F)^T \tag{3}$$

with $g^{F_i} = |\sum_a g_a^{F_i} \hat{v}_a| / (\sum_a |\hat{v}_a|^2)^{\frac{1}{2}}$ and $\{\omega_i, i = 1, \cdots, n_F\}$ the set of diagonalized projection matrices $(\omega_i)_{jj'} = \delta_{ji}\delta_{j'i}$. $\hat{v}_a \equiv < \phi_a^0 >$ $(a = 1, \cdots, n_H)$ are Vacuum Expectation Values (VEV's) which will develop from the Higgs bosons after SSB. $g_a^{F_i}$ are the arbitrary real Yukawa coupling constants. By convention, we choose $S_a^F = 0$ for $a = n_H$ to eliminate the non-independent parameters. S_a^F $(a \neq n_H)$ are the arbitrary off-diagonal real matrices. g^{F_i} are introduced so that a comparison between the diagonal and off-diagonal matrix elements becomes available. ζ_F is a conventional parameter introduced to scale the off-diagonal matrix elements with the normalization $(S_1^F)_{12} \equiv 1$ and $(S_a^F)_{ij}$ being expected to be of order unity (some elements of S_a^F may be off by a factor of 2 or more). $O_{L,R}^F$ are the arbitrary orthogonal matrices. Note that the above parameterization is general but very useful and powerful for our purposes in analysing various interesting physical phenomena.

In general, one can always choose, by a redifinition of the fermions, a basis so that $O_L^F = O_R^F \equiv O^F$ and $O^U = 1$ or $O^D = 1$ as well as $O^E = 1$ since the neutrinos are considered to be massless in this model. In this basis, the AGUFS and PCNF then imply that

$$(O^F)_{ij}^2 \ll 1 \ , \qquad i \neq j \ ; \qquad \zeta_F^2 \ll 1 \ . \tag{4}$$

where O^F describe the AGUFS in the charged currents and ζ_F mainly characterizes the PCNF. Obviously, if taking $\zeta_F = 0$, it turns to the case of NFC at tree level. Furthermore, when $\zeta_F = 0$ and $O^D = O^U = 1$, the theory possesses global $U(1)$ family symmetries.

We then conclude that the smallness of the CKM mixing angles and the suppression of the FCNSI can be attributed to the AGUFS and PCNF and can be regarded as being naturally in the sense of the 't Hooft's criterion [7]. It is actually manifest since exact global U(1) family symmteries demand that all the off-diagonal interactions should disappear from the model.

Let us now present a detailed description for the model with VCPV and AGUFS. The physical interactions are usually given in the mass basis of the particles. For the

simplest 2HDM, the physical basis after SSB is defined through $f_L = (O_L^F V_L^f)^\dagger F_L$ and $f_R = (O_R^F P^f V_R^f)^\dagger F_R$ with $V_{L,R}^f$ being unitary matrices and introduced to diagonalize the mass matrices

$$(V_L^f)^\dagger (\sum_i m_{f_i}^o \omega_i + \zeta_F c_\beta \sum_{i,j} \sqrt{m_{f_i}^o} \omega_i S_1^F \omega_j \sqrt{m_{f_j}^o} e^{i\sigma_f(\delta - \delta_{f_j})}) V_R^f = \sum_i m_{f_i} \omega_i \tag{5}$$

with m_{f_i} the masses of the physical states $f_i = u_i, d_i, e_i$. Where $m_{f_i}^o$ and δ_{f_i} are defined via

$$(c_\beta g_1^{F_i} e^{i\sigma_f \delta} + s_\beta g_2^{F_i}) v \equiv \sqrt{2} m_{f_i}^o e^{i\sigma_f \delta_{f_i}} \tag{6}$$

with $v^2 = v_1^2 + v_2^2 = (\sqrt{2} G_F)^{-1}$, $c_\beta \equiv \cos\beta = v_1/v$ and $s_\beta \equiv \sin\beta = v_2/v$. $P_{ij}^f = e^{i\sigma_f \delta_{f_i}} \delta_{ij}$, with $\sigma_f = +$, for $f = d, e$, and $\sigma_f = -$, for $f = u$.

For convenience of discussions, it is simple to make the phase convention by writting $V_{L,R}^f \equiv 1 + \zeta_F T_{L,R}^f$. In a good approximation, to the first order in ζ_F and the lowest order in m_{f_i}/m_{f_j} with $i < j$, we find that $m_{f_i}^2 \simeq (m_{f_i}^o)^2 + O(\zeta_F^2)$ and for $i < j$

$$(T_L^f)_{ij} \simeq -(T_L^f)_{ji}^* \simeq c_\beta \sqrt{\frac{m_{f_i}}{m_{f_j}}} (S_1^F)_{ij} e^{-i\sigma_f(\delta - \delta_{f_j})} + O((\frac{m_{f_i}}{m_{f_j}})^{3/2}, \zeta_F) \tag{7}$$

$$(T_R^f)_{ij} \simeq -(T_R^f)_{ji}^* \simeq c_\beta \sqrt{\frac{m_{f_i}}{m_{f_j}}} (S_1^F)_{ji} e^{-i\sigma_f(\delta - \delta_{f_j})} + O((\frac{m_{f_i}}{m_{f_j}})^{3/2}, \zeta_F) \tag{8}$$

With this phase convention, the CKM matrix V has the following form

$$V = (V_L^U)^\dagger (O_L^U)^T O_L^D V_L^D \equiv V^o + V' \tag{9}$$

where $V^o \equiv (O_L^U)^T O_L^D$ is a real matrix and $V' \simeq \zeta_D [V^o T_L^d] + \zeta_U [V^o T_L^u]^\dagger$ is a complex matrix.

The scalar interactions of the fermions read in the physical basis

$$\begin{aligned} L_Y^I = \; & (2\sqrt{2} G_F)^{1/2} \sum_{i,j,j'}^{3} \{ \bar{u}_L^i V_{ij'} (m_{d_{j'}} \xi_{d_{j'}} \delta_{j'j} + \zeta_D \sqrt{m_{d_{j'}} m_{d_j}} S_{j'j}^d) d_R^j H^+ - \bar{d}_L^i V_{ij'}^\dagger (m_{u_{j'}} \xi_{u_{j'}} \delta_{j'j} \\ & + \zeta_U \sqrt{m_{u_{j'}} m_{u_j}} S_{j'j}^u) u_R^j H^- + \bar{\nu}_L^i (m_{e_i} \xi_{e_i} \delta_{ij} + \zeta_E \sqrt{m_{e_i} m_{e_j}} S_{ij}^e) e_R^j H^+ + H.C. \} \\ & + (\sqrt{2} G_F)^{1/2} \sum_{i,j}^{3} \sum_{k}^{3} \{ \bar{u}_L^i (m_{u_i} \eta_{u_i}^{(k)} \delta_{ij} + \zeta_U \sqrt{m_{u_i} m_{u_j}} S_{k,ij}^u) u_R^j + \bar{d}_L^i (m_{d_i} \eta_{d_i}^{(k)} \delta_{ij} \\ & + \zeta_D \sqrt{m_{d_i} m_{d_j}} S_{k,ij}^d) d_R^j + \bar{e}_L^i (m_{e_i} \eta_{e_i}^{(k)} \delta_{ij} + \zeta_E \sqrt{m_{e_i} m_{e_j}} S_{k,ij}^e) e_R^j + H.C. \} H_k^0 \end{aligned} \tag{10}$$

with (in the above good approximations)

$$\xi_{f_i} \simeq \frac{\sin\delta_{f_i}}{s_\beta c_\beta \sin\delta} e^{i\sigma_f(\delta - \delta_{f_i})} - \cot\beta \ , \tag{11}$$

$$S_{ij}^f \simeq s_\beta^{-1} (e^{i\sigma_f(\delta - \delta_{f_j})} - \frac{\sin\delta_{f_j}}{\sin\delta}) (S_1^F)_{ij} \ , \qquad S_{ji}^f \simeq s_\beta^{-1} (e^{i\sigma_f(\delta - \delta_{f_i})} - \frac{\sin\delta_{f_j}}{\sin\delta}) (S_1^F)_{ji} \ . \tag{12}$$

$$\eta_{f_i}^{(k)} = O_{2k}^H + (O_{1k}^H + i\sigma_f O_{3k}^H) \xi_{f_i} \ ; \qquad S_{k,ij}^f = (O_{1k}^H + i\sigma_f O_{3k}^H) S_{ij}^f \ . \tag{13}$$

where O^H_{ij} is the orthogonal matrix introduced to redefine the three neutral scalars $\hat{H}^0_k \equiv (R, \hat{H}^0, I)$ into their mass eigenstates $H^0_k \equiv (h, H, A)$, i.e. $\hat{H}^0_k = O^H_{kl} H^0_l$ with $(R + iI)/\sqrt{2} = s_\beta \phi^0_1 e^{-i\delta} - c_\beta \phi^0_2$ and $(v + \hat{H}^0 + iG^0)/\sqrt{2} = c_\beta \phi^0_1 e^{-i\delta} + s_\beta \phi^0_2$. Here $H^0_2 \equiv H^0$ plays the role of the Higgs boson in the standard model. $H^\pm$ are the charged scalar pair with $H^\pm = s_\beta \phi^\pm_1 e^{-i\delta} - c_\beta \phi^\pm_2$.

By explicitly giving the new interactions, we now briefly discuss in this short paper their main features and summarize the most interesting physical phenomena arising from these interactions. The systematic analyses and detailed calculations are presented in a longer paper[8].

1) We observe that if the relative phase between the two VEV's is nonzero, each fermion (f_i) and neutral scalar H^0_k are then characterized not only by their physical mass m_{f_i} and $m_{H^0_k}$ but also by a physical phase δ_{f_i} and $\delta_{H^0_k} \equiv arg(O^H_{1k} + i\sigma_f O^H_{3k})$ respectively. This shows that the Higgs mechanism provides not only a mechanism for gaving mass to the bosons and the fermions, but also a mechanism for generating CP-phase of the bosons and the fermions.

2) All the vacuum-induced CP violations can be classified into four types of mechanism according to their origins and/or interactions. To be more clear, we emphasize as follows

Type-I. The new type of CP-violating mechanism [5, 8] which arises from the induced complex diagonal Yukawa couplings ξ_{f_i}. Such a CP violation can occur through both charged- and neutral-scalar exchanges.

Type-II. Flavor-Changing SuperWeak (FCSW)-type mechanism. This type of mechanism also occurs through both charged- and neutral-scalar exchanges and is described by the complex coupling matrices S^f_{ij} in this model.

Type-III. The induced KM-type CP-violating mechanism which is characterized in this model by the complex parameters $\zeta_F T^f_L$ and occurs in the charged gauge boson and charged scalar interactions of the quarks.

Type-IV. The Scalar-Pseudoscalar Mixing (SPM) mechanism which is described by the mixing matrix O^H_{kl} and the phases $arg(O^H_{1k} + i\sigma_f O^H_{3k})$. This type of CP violation appears in the purely bosonic interactions and also in the neutral-scalar-fermion interactions in this model. In general, SPM mechanism can also occur in the charged-scalar-fermion interactions when there exist more than two charged scalars, for example, the Weinberg 3HDM.

3) Without making any additional assumptions, m_{f_i}, V_{ij}, δ_{f_i} (or ξ_{f_i}), δ, $\tan\beta$, ζ_F, $(S^F_1)_{ij}$

(or S^f_{ij}), $m_{H^0_k}$, m_{H^+} and O^H_{kl} are in principle all the free parameters and will be determined only by the experiments. Nevertheless, from the AGUFS and PCNF, we can draw the general features that $V^2_{ij} \ll 1$ for $i \neq j$ and $\zeta^2_F \ll 1$. The m_{f_i} and V_{ij} already appear in the SM and have been extensively investigated. For the other parameters, it is expected that $(S^F_1)_{ij}$ are of order unity. Moreover, in order to have the FCNSI be suppressed manifestly, it is in favor of having $\tan\beta > 1$ and $|\sin\delta_{f_j}/\sin\delta| \lesssim 1$ (see eq.(12)). The diagonal scalar-fermion Yukawa couplings $\eta^{(k)}_{f_i}$ or ξ_{f_i} can be, for the light fermions, much larger than those in the SM and may, of course, also be smaller than those in the SM (the latter case appears to happen for heavy top quark). Nevertheless, the former case is more attractive since it will result in significant interesting phenomenological effects. The most interesting choice for large ξ_{f_i} is $\tan\beta \gg 1$ since it favors the suppression of the FCNSI.

4) From the established $K^0 - \bar{K}^0$ and $B^0 - \bar{B}^0$ mixings, we obtain that $\zeta_D/s_\beta < 10^{-3} m_{H^0_k}/GeV$. From the current experimental bound of the $D^0 - \bar{D}^0$ mixing, i.e. $\Delta m_D < 1.3 \times 10^{-4}$ eV, we have $\zeta_U/s_\beta < 3 \times 10^{-3} m_{H^0_k}/GeV$. Note that this can only be regarded as an order-of-magnitude estimation since in obtaining these values we have used the vacuum insertion approximation for the evaluation of the hadronic matrix elements. From the established CP-violating parameter ϵ, it requires either to fine-tune the parameters δ_d , δ_s, $arg(O^H_{1k} + iO^H_{3k})$, $(S^D_1)_{12}$ *et al*, so that the effective CP-phase is of order 10^{-2} or to choose $\zeta_D/s_\beta \lesssim 10^{-4} m_{H^0_k}/GeV$. For the latter case, the CP-violating phases are indeed generically of order unity.

5) To see how the various mechanisms play the role on CP violation and provide interesting physical phenomena, let us consider the following three cases:

(i) when $\zeta_F/s_\beta \ll 1$ with $(S^F_1)_{ij} \sim O(1)$, $m_{H^+} < v = 246$ GeV and $|\xi_i| \gg 1$ $(i \neq t)$, it is obvious that only the new type of CP-violating mechanism (type-I) plays an important role. The effects from the FCSW-type and KM-type mechanisms are negligible.

In this case, the CP-violating parameter ϵ can be fitted from the contributions of the long-distance dispersive effects[9, 10, 11] through the π, η and η' and/or short-distance box graph with charged scalar exchanges. This is easily implemented in our model through choosing appropriate parameter $Im(\xi_s\xi_c)$ and/or $Im(\xi_s\xi_c)^2$, respectively, for a given mass m_{H^+}. The ratio ϵ'/ϵ is expected to be of order 10^{-3} from the long-distance contribution which was first correctly estimated by Donoghue and Holstein[10] and has generally been discussed

in [11], and from the tree level diagram with charged scalar exchange. The latter case is easily reached by choosing appropriate parameters $Im(\xi_s\xi_d^*)$ and $Im(\xi_s\xi_u)$. The neutron EDM d_n can be consistently accommodated by choosing other independent parameters, such as $Im(\xi_d\xi_c)$ and $Im(\eta_d^{(k)} - \eta_u^{(k)})^2$ for the one-loop contribution with charged scalar and neutral scalar exchanges respectively, and $Im(\xi_t\xi_b)$ and $Im(\eta_t^{(k)})^2$ for the Weinberg gluonic operator contribution with charged scalar and neutral scalar exchanges respectively, as well as $Im(\xi_t\xi_q)$ $(q = d, s, u)$ for the quark gluonic chromo-EDM. The electon EDM d_e from Barr-Zee two-loop mechanism [14] is expected to be in the present experimental sensitivity for appropriate values of $Im(\eta_t^{(k)}\eta_e^{(k)})$ and $Im(\eta_t^{(k)}\eta_e^{(k)*})$ as well as $O_{2k}^H Im\eta_e^{(k)}$. CP violation in the hyperon decay can also be significant in this case. Based on the general analyses in [12], we have, for example, the CP asymmetry observable $A(\Sigma^\pm \to n\pi^\pm) \sim 10^{-3}$. Direct CP violation in B-meson decay is, however, small in this limit case. Nevertheless, T-odd and CP-odd triple-product correlations could be substantial in the inclusive and exclusive semileptonic decays of B-meson into the τ leptons.

In addition, by including the new contributions to the neutral meson mixings from the box diagrams with charged-scalar exchange, the mass difference Δm_K can be reproduced by a purely short-distance analysis when $|\xi_c| \gg 1$. For example, for $B_K = 0.7$, and $m_{H^+} = 100$ GeV, it needs $|\xi_c| \simeq 13$. When $|\xi_t| \sim 1$, $B^0 - \bar{B}^0$ and $B_s^0 - \bar{B}_s^0$ mixings can also receive a contribution as large as the one in the standard model.

(ii) when $10^{-4} m_{H_k^0}/GeV \lesssim \zeta_D/s_\beta < 0.1$, $\zeta_U/s_\beta < 0.3$ for $m_t = 150$ GeV and $(S_1^F)_{ij} \sim O(1)$,, $|\xi_i| \sim 1$, both the new type of CP-violating mechanism and the induced KM-type mechanism become less important and the parameter ϵ is then accounted for by the FCSW-type mechanism (type-II) together with the SPM mechanism (type-IV). If the CP-violating phases are indeed generically of order unity, thus the ratio ϵ'/ϵ becomes unobservable small ($\sim 10^{-6}$). In this case, its effects in the B-system are also small.

(iii) when $\zeta_D/s_\beta \sim 0.2$ and $\zeta_U/s_\beta \sim 0.6$ for $m_t = 150$ GeV, $c_\beta \sim s_\beta$, $|\xi_i| \sim 1$ and $m_{H_k^0} \gg v = 246$ GeV, i.e., neutral scalars are very heavy, then the CP-violating mechanism is governed by the induced KM-type mechanism. But it could be still different from the standard KM-model if the charged scalar is not so heavy, this is because the new contributions from diagrams with charged-scalar exchange can be significant. Therefore only when the charged scalar also become very heavy, the induced KM-type mechanism then approaches

to the standard KM-model which have been extensively studied [13].

It is seen that precisely measuring the direct CP violation in kaon (and hyperon) decays and the direct CP violation in B-system as well as the EDM's of the electron and the neutron are very important for clarifying origin and mechanisms of CP violation. For instance, if the direct CP violation in kaon decay is big and of order 10^{-3}, the electron EDM is also in the present observable level, while direct CP violation in B-system is unobservable small, we then conclude that the new type of CP-violating mechanism will be important.

Based on the assumption of the AGUFS and PCNF, the mass of the scalars could be less constrained from the indirect experimental data. Searching for these exotic scalars is worthwhile at both e^+e^- and hadron colliders. It is believed that the mechanisms of CP violation discussed in this model should also play an important role in understanding the baryogenesis at the electroweak scale[15]. In particular, its requirement for relatively light Higgs bosons is in favor of our model. We may conclude that if one Higgs doublet is necessary for the generation of the mass of the bosons and the fermions, then two Higgs doublets are needed for origin and phenomenology of CP violation and also for baryogenesis at the electroweak scale.

Finally, I would like to remark that as this model is the simplest extension of the Standard Model, we do not expect to be able to answer the questions which also appear in the standard model, such as many free parameters and the hierarchic properties of the parameters. We have also restricted ourselves in this paper to the weak CP violation and have ignored the strong CP problem. What we have shown is that such a simple 2HDM with VCPV and AGUFS possesses very rich phenomenological features, in particular on the phenomenology of CP violation. What we may do is to determine and/or restrict all the physical parameters from the direct and/or indirect experimental measurements, just like what we have been doing for the Standard Model.

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[15] For a review see A.G. Cohen, D.B. Kaplan, and A. E. Nelson, Ann. Rev. Nucl. Part. Sci. **43**, 27 (1993).